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STATISTICS IN ANCIENT HISTORY

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Statistics in Ancient History

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Abstract

This paper uses new data to extend the argument that there was an integrated wheat market in the late Roman Republic and early Roman Empire. I explore the meaning of randomness when data are scarce, and I investigate how we recreate the nature of ancient societies by asking new questions that stimulate the discovery of more information. The case for a prosperous Roman society extending the length of the Mediterranean Sea is strong. This paper draws on and extends work reported in my new book: *The Roman Market Economy* (Princeton, 2013).

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Statistics in Ancient History

I assume we all believe in facts. Whether we study science or economics or history, we base our conclusions on facts or, as they are called frequently, observations. When we turn to ancient history, we quickly discover there is lots of information about the ancient economy, but little that economists would classify as data (Temin, 2006). We therefore need to use the scraps of evidence that have survived for two thousand years to construct a view of ancient societies. The resulting intellectual edifice will be speculative and subject to revision as more data are found. I explore in this paper how to extract the most information from the sparse data we have. This approach also suggests how to incorporate new data when they appear and update our views.

I argue that statistics provide an illuminating tool to aid understanding of the data we have. This has the corollary that there is rather surprising information that a Mediterranean wheat market operated well during the early Roman Empire. For economists, I explore the advantages and limitations of a small-sample regression—topics interesting enough to econometricians that the first regressions in this paper are taught annually to economics graduate students at MIT. For ancient historians, I examine how we extrapolate from occasional comments made in speeches and letters to Roman society as a whole. This paper draws on research originally published in Kessler and Temin (2008) and extended further in my book (Temin, 2013).

I use statistics here to test the hypothesis that the Romans had created the conditions for trade from one end to the other of the Mediterranean Sea by their Pax Romana. This may not be startling to ancient historians at this level. But if this market was dense enough to equalize prices around the Mediterranean, that would be remarkable. I show that is exactly what happened for the most widely traded good, wheat, in the late Roman Republic and early Roman Empire. Note that this is not gold or jewelry that is so high value that it can be transported easily; it is a bulk commodity for mass consumption.

If there had been a unified wheat market, the main market would have been in the city of Rome, where the largest number of potential consumers lived and the center of imperial administration was located. In other words, Rome was where the largest supplies and demands for wheat would have come together and where the price of wheat consequently would have been set. The price would have varied over time as supplies fluctuated due to harvests across the Roman world, storms affected the cost of transportation, and government actions altered the value of the currency. Normal variations in supplies and demands elsewhere in the Empire would have affected the price, although most fluctuations would have been small relative to the total production and the consumption at Rome. Most places outside of Rome would have had an excess supply of wheat, and the price would have been set in Rome where the excess supplies and the largest excess demand came together. When local places were isolated, there could have been excess local demand as well as excess local supply, that is, local famines as well as local gluts.

Under these circumstances, wheat outside of Rome would be valued by what it was worth in Rome. Wheat at Palermo in Sicily, for example, normally would be worth less than wheat in Rome because it would have to be transported to Rome to be sold. The price of wheat in Sicily would be the price of wheat in Rome less the cost of getting wheat from Sicily to Rome. This would be true almost always, but there undoubtedly were circumstances when it was not. If storms prevented the shipment of grain to Rome, the Sicilian price might temporarily deviate from the level set by the price in Rome. If a harvest failure in Sicily created a local famine, the price of wheat in Sicily would rise above the level indicated by the Roman price until new wheat supplies could be brought in. In the absence of extreme events like these, a unified market would keep Sicilian prices near the Roman price less the transportation cost.

More concretely, competition would determine Sicilian prices if there was a unified market. If the Sicilian price of wheat rose above the Roman level minus transportation costs, it would not make sense for merchants to buy wheat in Sicily to sell in Rome. The amount of wheat demanded in Sicily would fall, and the price consequently would fall as well. If the Sicilian price of wheat fell below the Roman level minus transportation costs, merchants would increase the amount of wheat they would buy in Sicily, for they could make an unusually high profit by taking it to Rome and selling it there. Merchants would bid against each other, raising the Sicilian price.

Wheat at Lusitania in Spain would be worth less than wheat at Palermo because it was further from Rome. The cost of transporting wheat from Spain to Rome was larger than the cost of bringing it from Sicily, and the price of wheat in Spain correspondingly would be lower. The reasoning is exactly like that for Sicily, only the transport cost is different. But while each price is compared to that in Rome, the price in Spain would be lower than the price in Sicily if there were a unified market. In fact, wheat around the Mediterranean would be worth less than the price at Rome, with the amount less depending on the distance from Rome. We do not know the transport cost in any detail, but we are reasonably sure that it rose with distance. If there was a unified wheat market, therefore, the price of wheat would have decreased as one moved farther and farther from Rome. As Adam Smith (1776, Book 3, Chapter 1) stated it: "The corn which grows within a mile of the town, sells there for the same price with that which comes from twenty miles distance."

If there were not a unified market, if there were only independent local markets, then there would not be any relationship between local and Roman prices. There would be prices in local markets that would be determined by local conditions. The prices might move together at some times, if storms across the Mediterranean caused simultaneous harvest failures everywhere or currency debasements caused prices to rise everywhere, but they would not in general be related one to another; any single identity of prices could be a coincidence. If we find several wheat prices in different places, however, we can test whether the pattern we find is due to coincidence or an underlying market process.

The question is not whether one or the other of these ideal types was observed, whether there was an efficient market or that there were no factors unifying separate local markets. It is rather whether the historical experience lies closer to one end of a continuum than the other. Many interventions into Roman markets and local actions elsewhere around the Mediterranean are well known. There must have been at least occasional local grain shortages and even famines. The question then is whether the normal state of affairs was one of interconnected markets, so that prices in different places typically were related, or one of separated and independent markets. In the latter case, we should not observe any systematic relationship between the location and the price of grain.

I approach this test in three steps, the first of which uses a small set of wheat prices from varied locations from Rickman (1980). This familiar sample provided a way to examine monetary integration at least provisionally. When dealing with fragmentary data it is necessary to collect a sample that is not determined by the desired outcome. Rickman was writing about the Roman wheat market, and he collected his sample to show habitual prices in different places. The sample, albeit small, therefore looks like a random sample. It is, in Rathbone's (2003, 201) felicitous phrase, "thin but nicely random." The second step is to check these results with a new data set in Rathbone (2011). These data were collected to exhibit the surviving prices from around the Mediterranean. They overlap Rickman's sample, but the two authors made different choices in collecting data that allow us to delimit more precisely the extent of the Roman Mediterranean wheat market. The third step is to consider an even newer data set from Bransbourg (2012) and the criticisms Bransbourg levels at the first step in this analysis.

I use a simple model for two reasons. It supplies a clear representation of Roman trade around and across the Mediterranean where wheat prices in outlying provinces were related to those in the city of Rome. Given the extremely limited data on Roman prices, no more complex model could be tested. The simple model treated here also is compatible with a complex pattern of actual Roman trade. There must have been trades between provinces, local scarcities—labeled famines by ancient authors—where wheat was shipped to these localities rather than Rome, and times when storms or wars limited flows of wheat around the Mediterranean. Yet the extant Roman wheat prices suggest strongly that these special cases were unusual, that any historical diversity of trade was dominated by the pull of trade to the city of Rome in most times and places during the late Republic and early Empire.

The Rickman sample consists of price pairs in outlying locations and in Rome at roughly the same time, accumulating six price pairs in almost two centuries ranging from the late Republic to the early Empire. This is not an overwhelming amount of evidence, but it is enough to test whether the patterns in the data are random or not. In each case the Roman price was subtracted from the price at the distant location to give a price differential. Wheat prices at Rome were subject to slow inflation according to Rickman and Duncan-Jones (1982). I characterize this period as having stable prices elsewhere, with an allowance for slow and gradual price changes which will be described below (Temin, 2013).

I describe the price observations in the order of their distance from Rome, calculated as straight-line distances on a map. This of course is only an approximation to the actual distance that wheat traveled, and this added randomness reduces the possibility of finding evidence of an integrated market. If observations are randomly drawn from a population, then even a few observations give information about the whole population. All of the statistical theory I draw on rests on the assumption of a random sample. How can we know whether the observations are random, as Rathbone's comment asserts? Two arguments are relevant here. First, the process of survival for two millenniums is the product of many intervening events (Greenblatt, 2011). Many independent actions add up to randomization. Second, the data used in a regression can be compared to regressions on other samples from the same population, indicating whether the initial results hold up. This is the subject of this paper.

The closest price was from Sicily and came from Cicero's *Verrine Orations*. One of his accusations was that Verres did not transact business at the market price, even though he acknowledged its level in a letter (Cicero, 2 *Verr*. 3. 189). This observation, like most of the others, reports the prevailing local price in round numbers. Since the observation is general rather than the record of any transaction, it is likely to be only approximate. This casual quality of the data also militates against finding any systematic relationship between prices. It introduces more noise into any relationship of the prices being paid because of the unknown difference between the reported averages and actual prices. These implications about the difficulty of drawing conclusions all depend on the randomness of the observations. If there are systematic biases in the observations, then something more than these general rules are needed.

The second price came from Polybius (34.8.7) in his discussion of conditions in Lusitania. As before, this is a general statement about the prevailing price. While it is good to have an average, the casual quality of the averaging process again adds noise into any comparison of prices in different places.

The third price comes from the Po Valley in Italy; it is another observation by Polybius (2.15.1). While this observation is closer to Rome than the first two prices, I made an exception to the general rule of measuring distance. The Po Valley was linked to Rome more by rivers rather than sea, although the transport of a bulk commodity like wheat may well have gone by sea (Harris, 1989). I calculated the distance in two ways that fortunately give the same distance. Diocletian's *Price Edict* fixed river transport prices at five times the level of sea transport, and I first took the cost of river transport from the Po Valley to have been five times as expensive as by sea. This evidence dates from over a century later than any of the other prices, but I assumed the ratio of sea and river transport costs remained constant over time as argued by Greene (1986, 40) and included the Po valley in the price data by multiplying the distance from Rome by five. In addition, the distance by sea from the Po Valley to Rome is the same as the distance I calculated from the Diocletian Edict. The sea distance is not a straight line, and this observation therefore is slightly different from the others even if measured by sea. Despite the small sample, there is enough data to test whether this unusual attention to distance for this observation affects the statistical result.

The fourth price comes from an official intervention in the local market. An inscription records that the wheat price in Pisidian Antioch was high in a time of scarcity. The normal price was eight or nine *asses* per *modius*; the acceptable limit price was one *denarius* per *modius* (*AÉ*1925, no. 126b). This inscription reveals several important aspects of the Mediterranean wheat market in addition to reporting the normal price. The need to damp down famine prices indicates that local markets were subject to local scarcities; they were not so well linked that wheat from elsewhere would be brought in instantly in response to a local shortage. The apparent success of such interventions, in this case limiting the price to double its normal range, indicates that many famines were not severe.

For Egypt, I preserve the spirit of Rickman's data but improve on his data since Rathbone (1997) reworked the sale prices that Rickman took from Duncan-Jones. I averaged seven Egyptian prices from the "famine" of 45-47 CE to get a price for Egypt. Rathbone argued that these prices were unusual, but the previous discussion suggests that they may not be far from average. We of course cannot know how unusual these prices were, and any special conditions introduce noise into our data. The Egyptian prices also come from agricultural areas, not from a Mediterranean port. The purported famine would have raised the price, but using country prices would have depressed it compared to those at a port. These offsets introduce added uncertainty into the accuracy of this observation since there is no reason to expect them to be exact offsets. The average of Rathbone's seven prices was seven *drachmae* per *artaba*. These prices in Egyptian currency and units were converted to HS per *modius* by following Duncan-Jones (1990, 372) and dividing by 4.5.

The final observation, from distant Palestine, is taken from Tenney Frank's *Economic Survey*; it too is an average of a few actual transactions (Heichelheim 1938, 181-83).

All of these prices were compared with roughly contemporaneous prices at Rome. Rickman argued that the price of wheat at Rome was between three and four HS per *modius* in the late Republic, rising to five to six HS in the early Empire. Duncan-Jones confirmed the general price level; Rathbone confirmed the inflation, at least for Egypt where the data are more abundant. The order of observations turns out to be almost chronological even though the order of exposition was by distance. There are six prices in almost two centuries. This is not an overwhelming amount of evidence, but it is enough to test whether the patterns in the data are random or not. In each case the Roman price was subtracted from the price at the distant location to give a price differential. More prices come to light all the time, but this "thin but nicely random" sample provides a way to answer the question at least provisionally.

The prices and the differences between the prices at Rome and the local prices are listed in Table 1. The differences are all negative, consistent with the story of an integrated market and with general observations that agricultural prices were lower outside Rome (Garnsey 1998, 241). Wheat prices clearly were lower outside of Rome than in Rome itself. The straight-line distances from each location to Rome also are in Table 1. I test whether the differences between prices in these provincial locations and the price at Rome were proportional to their distance to Rome. The value of a statistical test is that one can say with some precision how unlikely it is that the observed result would be found if the data were generated by pure chance. I described how the data are only approximate. Each approximation introduces an added element of randomness into the data, increasing the probability that any observed pattern is simply noise.

The price differentials are graphed against the distance to Rome in Figure 1. The results are quite striking; prices were lower in places further from Rome, and the price differentials appear almost proportional to the distance from Rome. These prices come from all over the Mediterranean and from various times in the late republic and early Empire. If there were not a unified grain market, there would be no reason to expect a pattern in these prices. Even if there was a unified market, our inability to find more prices or more accurate transportation costs might have obscured any true relationship among the prices. Yet Figure 1 reveals a clear picture.

It may appear as if the picture in Figure 1 could only *suggest* such a story. It seems like a tiny bit of evidence on which to hang such a grand story of universal monetization and market integration. However, regression analysis can be used to evaluate how likely it is that a picture like Figure 1 could arise by chance. We can test the probability that the separate areas of the early Roman Empire were isolated and out of economic connection with Rome. Their prices would have been determined by local conditions, including perhaps the degree of monetization. There would have been no connection between the distance to Rome and the level of local prices.

We start by trying to draw a line that relates the price difference between the local price and the Roman price to the distance from Rome. We then adjust the line to make it the best description of the data in the sense that it minimizes the squared distance of the individual observations from the line. (We use the square of the distance to minimize the distance from points both above and below the line and to simplify the mathematics.) This process of regression analysis also is known as the method of "least squares," and the resulting least-squares line is the regression line. It is shown in Figure 2.

One of the values of regression analysis is that it generates tests of the hypotheses being tested. We can ask if an apparent relationship between the price discount and the distance from Rome is illusory, a result of observing only a few prices, rather than the result of a systematic process. In order to draw this line, we assumed that there was a relationship between the distance from Rome and the price discount. Regression analysis provides a test whether there is such an association in the data. This test tells us how unlikely it is for us to find a line like the one shown in Figure 2 by chance. Assume that the prices we gathered from Rickman were randomly drawn from an underlying distribution of price observations. In another world, different prices could have survived from this same distribution. Taking account of the random quality of the observations we actually have, how unlikely is it for us to find the line in Figure 2 by chance?

Regression analysis acknowledges that the slope of the line in Figure 2 is not known with certainty. It is the best line that can be drawn with the data at hand, but it is subject to errors deriving from the incomplete sampling of the underlying distribution. In the jargon of regression analysis, the slope of the line has a standard error. If all the points in Figures 1 and 2 lay in a straight line, then the slope of the regression line would be clear, and the standard error of the slope would be close to zero. If the points are spread out as they are in the figures here, then the line is not known as clearly, and there is a chance that the line has no slope at all, that is, that there is no relationship between the distance from Rome and the price difference.

The test is to compare the size of the slope, the coefficient in the regression, with the size of its standard error. If the coefficient is large relative to the standard error, then it is unlikely that the line was a random finding without support in the price data. On the other hand, if the coefficient is small relative to its standard error, then it is possible that even though the regression line has a slope, there is no underlying relationship between the price and distance. Statisticians call this ratio a t-statistic, and they have calculated tables that can translate t-statistics into probabilities that the line is observed by chance.

The tables take account of degrees of freedom, that is, the number of observations minus the number of coefficients. It takes two variables to define a line, its slope and its position (its height in the figures). With six observations and two variables, there are four degrees of freedom. Omitting the observation with river transport reduces the number of observations by one and the degrees of freedom to three. The t-statistic has to be larger with such few degrees of freedom than with more degrees of freedom to show that a given regression line is unlikely to be the result of chance.

One might think that the data—composed of only a few, badly observed values—are too poor for statistical analysis. Statistics however are the best way of distinguishing signal from noise; they are particularly useful when there is a lot of noise in the system. They give us a precise sense of how unlikely it is that any putative pattern we think we observe would have been generated by random processes, that is, how unlikely it is that what looks like a pattern actually is noise. The value of statistics is that we can test a formal hypothesis, namely that wheat prices around the Mediterranean Sea were related in a simple way to those at Rome. We also can derive an explicit probability that this hypothesis is true, given the observations we have.

The key, again, is randomness. If observations are randomly drawn from a population, then even a few observations give information about the whole population. There is a lot of theory that analyzes how difficult this is. In particular, errors in the transcription or treatment of data militate against finding stable results to be generalized because they increase the randomness of the observations. In other words, finding a pattern in these few data points is quite remarkable.

Errors in variables are a common problem in doing regressions. We often hypothesize a relationship between two variables—like the price in Rome and the price in Egypt—but cannot observe one or the other of them precisely. We then use a proxy such as the occasional price that happens to be mentioned in a surviving document. The errors introduced by such a procedure have been studied, and their effects are well known. The extra uncertainty introduced by using imperfect proxies reduces the explanatory power of regressions and tends to result in coefficients that are near zero; the addition of noise through imperfect observations makes the results look more like noise. The well-known scarcity of Roman prices therefore makes it very hard to find a pattern in them. When a pattern is found, however, it indicates both that there is a strong relationship between the prices and that the observations we have are reasonably representative.

Statistical tests are needed to tell if the observed pattern could be the result of chance. The results of four separate regressions of the price differential on the distance from Rome are shown in Table 2. Since the transportation from Bologna was by river rather than sea, I was not sure that the correction for the relative cost of transport was accurate and tried the regressions both with and without the Bologna data point. In addition, in the bottom two regressions the price differentials are expressed in logarithms to measure the proportional change in them. Since there are no logarithms of negative numbers, the signs in the bottom two regressions are changed. The dependent variable is the premium of the Roman price over the local price instead of the discount of the local price from the Roman price.

Several conclusions emerge from these results. The R^2 shown in the final column measures the share of the variance of the price differentials that is explained by these simple regressions. Using the price differentials themselves, the regression explains three-quarters of the variation. Using logarithms of the differentials, the regressions explain even more. This result confirms the impression in Table 2 and Figure 1 that distance from Rome was a powerful explanatory factor in determining wheat prices around the Roman Mediterranean.

T-statistics are shown in parentheses beneath the coefficients in Table 3, and they indicate whether the relationship between price differentials and distance was the result of chance. These statistics measure the probability that each coefficient is different from zero, taking account of the number of observations used to derive it as well as their variation. T-statistics above three indicate that there is less than one chance in twenty that the observed relationship between distance and price differentials was due to chance. In the more precise language normally used for regressions, the probability of observing the coefficients in the table if there were no relationship between the price of wheat and the distance from Rome is less than five percent in three out of four regressions and close to that probability in the fourth. The five percent value of the t-statistic for four degrees of freedom (six observations) is 2.8; for three degrees of freedom (five observations), 3.2. Higher t-statistics indicate lower probabilities that the observed relationship is the result of chance.

In other words, the regressions confirm with very high probability that there was a unified wheat market that extended from one end to the other of the Mediterranean Sea. Transport costs were roughly proportional to distance, and the effects of distance were larger than the idiosyncratic influences of particular markets and places.

The constant terms in these regressions were negative in the regressions for price discounts and positive in the regressions for the logarithms. They were not estimated as precisely as the relationship between distance and the price differentials, and they consequently could be the result of chance (as indicated by smaller t-statistics). The constant terms however are historically reasonable and indicate that not all costs were proportional to distance. There appear to have been other costs as well, albeit smaller and less well observed. These other costs were partly physical—the costs of transshipping wheat to and from sea-going ships—and partly administrative—port charges and taxes. Their presence does not detract from the effect of distance or the evidence in favor of a unified wheat market.

Finally, it does not make a difference whether Bologna is included or not. Removing this observation reduced our comparisons to five, but it did not affect the proportion of the variance explained or the evidence that the relationship of distance to price differentials was not random. The t-statistics take account of the reduction in the number of observations to calculate the probability that the observed correlation was due to chance. The logic behind this finding can be seen in Figure 2. The observation for Bologna lies close to the regression line. Removing it therefore does not change the line.

The second step in this exploration is to compare these data with a newer data set from Rathbone (2011), an expanded version of the data in Rathbone (2009). At first glance, this looks like a larger data set, with 23 observations and more power to test hypotheses. It turns out however that the added data give us a way to clarify the previous results rather than to make a new start. We need first to consider how this sample was constructed. In Rathbones' words, they are the extant prices "which are significant for market behavior." In other words, they were not picked to prove a hypothesis, but rather to show what we know about Roman wheat markets. Again, thin but nicely random.

Eight of these observations are for prices at Rome. Rathbone recognized that the *annona* distorted the market at Rome, and he did not attempt to find a market price that prevailed in normal times. He presented high prices in severe shortages, although one of them is close to Rickman's Rome price, and state subsidized prices. He did not follow Rickman and try to estimate an average from these very diverse prices. I decided to ignore these Roman prices as being for unusual dire circumstances and irrelevant to the question of provincial prices. Without a set of prices at Rome, I used the prices elsewhere instead of discounting them from the Roman price and added a time variable to account for the slight inflation visible in Rickman's data. The result is to lose eight observations and add a variable, decreasing the degrees of freedom by nine.

For other observations, I used the average where Rathbone provided ranges. I disregarded the few prices where Rathbone—ever cautious about data—added question marks to the prices or dates and a few prices from "extreme shortages." I also discarded the observation for Judaea as being too imprecise and probably irrelevant. The timing was given only as the long second century, which is after the Judaean revolt. It is likely that the turmoil after the destruction of the Judean temple caused trade to be disrupted. In fact, the Talmud prohibited wheat exports (Heichelheim, 1938, 182). The date and effectiveness of this prohibition are not known, but it suggests that the kind of price arbitrage discussed earlier in setting up the regressions was not operative after the revolt. (I did not inquire into the timing of my Judaean observation in using the Rickman data, but removing the Judaean price does not affect the results in Table 3, although of course it decreases the degrees of freedom.)

I ended up with eight observations. I used them all and also tried omitting the observations on the Po Valley since the distance measure is problematical as noted already and an Egyptian price from the third century after inflation had picked up. The results are shown in Table 3, where it can be seen that these regressions reproduce the coefficients on distance in Table 2. The coefficients are the same size and known with the same precision. The regressions as a whole however do not have the same explanatory power as those from Rickman's data. Despite the overlap between the two data sets, there is more unexplained variation in this data set. In addition, when the two problematical observations are dropped, there are no more observations than in Table 1. Since there is an additional variable, the degrees of freedom are like the second and fourth regressions in Table 2 with only three degrees of freedom. As before, it is good that omitting these observations does not affect the results. The constant is larger than before because it includes an implied price at Rome in addition to any costs of taxes or transport to the city. The estimated inflation rate mysteriously is very large.

It is good that Rathbone's data confirms the effect of distance on price that I found in Rickman's data. There are some problems that should be acknowledged. Differing from my earlier regressions, I did not use all of Rathbone's data. I had good reasons for my selections, but I cannot be sure that the resulting data constitute another random sample. The reason is that I already knew what I wanted the regression to look like, and I may have selected data to show the pattern I desired. Even if I did not explicitly set out to reproduce my results, I may have done so unconsciously. To test the randomness of the Rickman sample, it would be better to have a data set constructed by someone not invested in the results in Table 2.

The third step in this argument uses such data. Bransbourg (2012) did not start out as supportive of my results. The first graph in his paper shows the effect of moving the measured distance for one of my observations, a move that he claims makes my regression "very weak to a point of near irrelevance." This claim of course is nonsense. It is clear that you get different answers with different data. To change the data after the results appear in order to change the results does not allow you to test hypotheses. If you do not believe in data, then you can reach any conclusion you desire. If you feel free to change the facts, then you leave the domains of history and economics.

Bransbourg also said that "statisticians try to avoid situations where they have to rely on a dozen or fewer observations." This is correct but irrelevant. If we had more Roman price data, we would use it. When I found more data for prices in Hellenistic Babylon, I used all the econometric tools I could to ask if these were market prices, if they moved in response to historical events, and other related questions (Temin, 2002). But we lack more prices for Rome in the late Republic and early Empire. If we had more data, we would use it. Given the limited number of observations, we console ourselves with calculations that require higher t-statistics for any level of significance with fewer observations. These higher levels keep us from making excessive claims for estimated coefficients when we have only 6 observations rather than six hundred.

After some more harsh words—"the equation as formulated [Table 2] cannot be statistically upheld"—Bransbourg set about collecting a new set of prices. He added more prices to those reported in Rickman, and he recalculated Rickman's data to provide what he considered more accurate distances and sometimes new values. Despite the overlap with Rickman's sample, the new data set provides a new sample from this ancient price distribution that can be used to see if another sample yields the same result as the first sample.

And the answer is … the new sample replicates the results of the original one. Despite Bransbourg's effort to discredit my results, he obtained the same results even as he stacked the deck against them. The results shown in Table 4 reveal that even with Bransbourg's data, the negative association between price and distance is clear. The first two regressions appear in Bransbourg's paper as reported here. I replicated the regressions, but I use his results here to make my emendations consistent with his work.

With his full data set of a dozen observations, he reproduced the significant effect of distance on price, but with a lower R^2. He concluded that the effect of distance explained far less of the variation of Roman prices than I claimed. Bransbourg suggested that the market may have worked better for coastal cities than inland ones, and tested this proposition in the second regression. Using only coastal cities, and reducing his sample size to the familiar half-dozen, he found that not only was the effect of distance clearer, but that distance from Rome explained 86 percent of the variation of prices around the Mediterranean.

If Bransbourg's reasoning is correct, then a regression of the other 6 observations—the ones from inland cities—should not show much effect of the distance from Rome. I did that regression and found exactly the opposite. The coefficient of distance was estimated precisely, and the regression line explained 87 percent of the price variation. This result (not shown in Table 4) suggested that distance was important, but it was slightly different for coastal and inland cities. I therefore did a regression with all 12 of Bransbourg's observations and an additional variable, a dummy for inland cities.

The results are shown in the third equation of Table 4. There the results of my original regressions clearly are reproduced. The effect of distance on wheat prices is clearly estimated and the regression explains three-quarters of the variation of Roman wheat prices around the Mediterranean once one makes an allowance for the difference between coastal and inland cities. The effect of the extra cost of transportation is not clearly estimated, but it appears that the price discounts from the price in Rome in coastal cities were about one *sestertius* per *modius* smaller than inland cities at the same distance from Rome.

This is perplexing. The effect of distance shows up well in the combined regression with 12 observations, but it puts the constant term higher for inland cities. In other words, inland cities at the same distance from Rome as coastal cities had *higher* wheat prices. I tried to see if this was due to an outlying observation. Bransbourg placed Antioch in Pisidia much farther from Rome by adding many sea-mile equivalents for overland transportation to the coast. I omitted this observation—as I did in Table 2 for the Po Valley—and obtained the final regression in Table 4. This regression, with 11 observations is almost exactly like the one above it with 12 observations; the extreme observation did not dictate the rise in the inland price. And the R^2 is as high as in the original regressions in Table 2.

I cannot resolve the issue of inland prices at this time. Perhaps all the inland cities have their distances in equivalent sea miles inflated in this data set. Perhaps there is another explanation. Nevertheless, the equations are stable and the coefficient on distance clear in all regressions. It appears that the influence of the Mediterranean market was as strong for inland cities as for coastal. While not totally distinct from the original Rickman sample, this sample shows similar patterns, reinforcing the randomness of the original sample.

Having justified the assumption of randomness to enable statistical distributions to be used, I turn to several more general objections that have been raised to this kind of test and its conclusion. The first objection is that prices were low outside Rome because coined money was scarce, not because transport to Rome was costly. This alternative cannot explain the prices in Table 1. Coins may have been scarce in Lusitania at the time of Polybius, but coins were abundant in the eastern Mediterranean where the monetized Greek economy preceded the Roman one. Wheat prices there were lower than in Lusitania, as can be seen from the figures. Distance from Rome is a much better predictor of prices than coin scarcity.

A second objection is that the prices are unrepresentative because they are notional, biased because the observers had political motives, or unrepresentative due to price fluctuations. Such errors in the price observations may have been present, although Polybius was a very careful historian, not liable to falsify his evidence to make a rhetorical point. As noted already, such errors in recording the "true" prices introduce noise into the relationship between the price differential and distance from Rome. If there was a great deal of this distortion, any existing relationship might be obscured. Since the regressions show such a relation, it means that the relationship between distance and price was a strong one, visible even through the noise introduced by casual or distorted price observations.

More formally, we can think of the observed prices being determined by the true prevailing prices, which we observe with an error due to our approximation. Then the dependent variable we used in the regression is the true price differential plus an error. That error would add onto the error of the regression and result in a lower t-statistic and R^2. Given that they both are large, the data show that this rough assumption in fact is quite good, that the observed prices appear to represent prevailing prices in a reasonable fashion.

Another related objection is that prices fluctuated during the year and observations may have come from different seasons. Again, this source of noise strengthens the results because the seasonal price variation introduces another source of noise into the hypothesized relationship. I suspect that the casual nature of the price observations has helped here. Travelers were told of the prevailing price, not sometimes the high price that obtains just before the harvest comes in and sometimes the low price following the harvest. The result appears to be a consistent set of prices. Phrased differently, while the few prices that have survived for two millennia are quite random, it is perverse to insist that any observed pattern has to be spurious. There does not seem to be a reason to throw out evidence from the ancient world on the grounds that the pattern must be as random as the observations.

Yet another objection to the use of these prices is that the argument is circular: I assume the data are sound because they support the hypothesis, but the test of the hypothesis requires the data to be sound. On the contrary, I assume that the observed prices are drawn randomly from a distribution of prices in the late Republic and early Roman Empire. I do not assume they are accurate or come from a particular kind of investigation or a particular time of year (as in the previous paragraph), and I compared my results with those from other data sets. Given that I am sampling from the population of wheat prices, the t-statistic tells us whether there is a relationship between price and distance. There is no more circularity here than in any statistical test of a hypothesis.

Another objection is that the samples are tiny, often only six price pairs or eight prices. The small samples are unfortunate, but no barrier to the test of this hypothesis. As noted above, the standard errors and t-statistics are corrected for degrees of freedom. Having few observations makes it easier to reject hypotheses, but it does not affect the validity of the test.

We would of course like to have many more prices, but there are no more to be found at this time. The new Rathbone sample has hardly more useable prices, and it confirms the main outlines of the test. Bransbourg had more observations and again confirmed the importance of distance from Rome in determining provincial wheat prices.

Rathbone's data set includes observations from periods of severe shortages. The few added observations do not give us information on the frequency of these shortages, but they remind us that the Mediterranean wheat market was subject to events that increased the difficulty and cost of shipping wheat across the sea. The market worked in general, but there was not enough storage to smooth out the difficulties that arose from time to time.

Some objections are more emotional than rational. Erdkamp (2005, 256) talks of "the weaknesses of the grain market." This is not an economic term; perhaps it refers to the occasional shortages. Seminar participants have said that if one data point of this small data set was moved, then the result would disappear. But choosing data points to make a result come out the way you want it makes the process circular; a statistical test only is possible when the data are chosen for reasons other than influencing the result of a test.

Bang (2008, 31) stated dramatically:

> Peter Temin argued that Finley was quite simply wrong; the economy of the Roman Empire represented just such a conglomeration ["an enormous conglomeration of interdependent markets"]. This is an extraordinary claim. One might conceivably imagine that some markets had begun to be linked by middle- and long-distance trade. But to see the entire economy, spanning several continents, as organized by a set of interlinked markets is quite another matter. It is doubtful whether the mature eighteenth-century European economy, outside some restricted pockets, could be described in such terms.

The last sentence reveals a difficulty with references to early modern European economic history that is all too common among ancient historians. Bang reported staples of early modern trade practices—reports from agents, family networks, need for supercargoes, etc.—as if they precluded long-distance trade. He quoted the boilerplate at the end of a typical agent letter saying that prices vary over time as evidence that planning is impossible, and he decried the Roman failure to develop bills of exchange without understanding that the Roman universal currency area obviated the need for such bills. In fact, eighteenth-century international trade stimulated the Industrial Revolution (Allen, 2009).

Bang also used an outmoded economic theory. He denied the presence of “Ricardian trade” by noting that complete specialization of Roman provinces did not take place (Bang 2008, 73-76). This is only a problem if Ricardo’s original formulation is used and no notice is taken of two centuries of elaboration of comparative advantage. Ricardo’s model still illuminates the principle of comparative advantage when we acknowledge there are two factors of production and prices change when countries approach specialization. The only difference is that the model used today allows for partial specialization if countries or regions are not too different. No ancient historian denies that Roman Egypt had a comparative advantage in wheat production.

All these objections come, I think, from two causes. First, the regressions challenge long-held beliefs about the primitivism of ancient societies. Second, ancient historians are prone to hazards of thinking identified by Daniel Kahneman. He argues that many people are prone to assuming that what you see is all there is instead of extrapolating from what they see. And he says that “people are prone to apply causal thinking inappropriately, to situations that require statistical reasoning (Kahneman, 2011, p. 77).”

This paper explored the usefulness of small-sample regressions when more observations are not available. As I said earlier, my econometric colleagues like to use these regressions to illustrate the usefulness of econometric theory because the students can calculate directly the significance of their results. They are taught regularly to graduate students at MIT. Economics increasingly is using larger and larger data sets, but every once and while a small data set is all that is available. It is useful to understand how useful such a small data set can be.

This paper presents evidence for the presence of a series of unified grain markets that stretched from one end of the Mediterranean to the other in the late Roman Republic and early Empire. The extent of the Roman market has been debated exhaustively, but evidence to date has been restricted to local markets. The presence of localized market activity has ceased to be controversial, but the question of market integration is still alive. The evidence produced here demonstrates that there was something approaching a unified grain market in the Roman Mediterranean.

Government interventions in wheat markets make it clear that the market could not prevent shortages even in Rome (Garnsey, 1999). The government intervened in the wheat market from time to time to lower prices and alleviate shortages, particularly under Augustus. It also is clear, even from what must be a partial list, that the known interventions were intermittent. The market for wheat was allowed to work on its own in other years. In addition, if traders expected the government to interfere when famine loomed, they might have been discouraged from trying to corner the market in adversity. Government intervention therefore may have dampened speculation and made the underlying pattern of prices easier to see.

Of course, there also were local famines, and local areas were not always connected to the market in Rome. Rathbone recorded examples of isolated markets—with prices that do not fit this regression line—showing examples of prices not connected to the regular market. The regressions demonstrate that there were many connections between far-flung Roman grain markets; only with more data will we be able to get a better idea how often outlying markets were connected to the major consuming market in Rome.

This paper also illustrates the usefulness of regression analysis in ancient history. This paper compiled existing information into a format that suggested the existence of a unified market, as in Figure 1. It also provides a test whether the observed pattern could have arisen by chance. Given the small number of observations, it always is possible that the pattern was simply a coincidence. Regression analysis allows us to quantify that possibility. The probability that the line in Figure 2 was due to chance is about five percent, that is, one in twenty. This is a far more precise estimate of the probability that we are observing an actual relationship than has been available previously. Given the scarcity of data and the prevalence of shortages, it is clear that regressions can only help interpret existing data, not provide additional information to provide definitive answers to all questions.

Finally, these regressions tested a very simple model of Roman trade, that there was a single wheat market across the whole Mediterranean. I tested this hypothesis with simple regressions with few degrees of freedom. Why should any ancient historian believe such a simple model and test? The purpose of a model is to provide an overall view of trade in Rome; it cannot explain every detail. Instead it provides an overview that helps our thinking. In this case, the regressions show that there were interconnected markets in the Mediterranean, but we also saw in the data that these markets did not work all the time or in all places. As expressed by Rathbone (2011):

> Unsatisfactorily thin as the Roman wheat price data are, they seem to suggest a partially integrated market, determined primarily by regional productivity and demand on the one hand, and on the other by the ease or difficulty of transport. Basically the major coastal zones of the empire were linked into a hierarchical structure with the highest price band in Rome and Campania, where demand most exceeded production, a middle band in Sicily, the Greek cities and, to some extent, Judaea, and the lowest band in Egypt, which though not coastal was linked to the Mediterranean by the Nile, and where production most exceeded demand.

Rathbone sees a hierarchy where I see continuity, but we describe much the same conditions. He notes that the excess of demand over the supply of wheat was greatest in and around Rome, and he says other regions were “linked into a hierarchical structure.” This is the structure of an interconnected set of Mediterranean markets that extended—with occasional interruptions and the probable exception of turbulent Judaea—from Egypt to Lusitania in the late Roman Republic and early Roman Empire.

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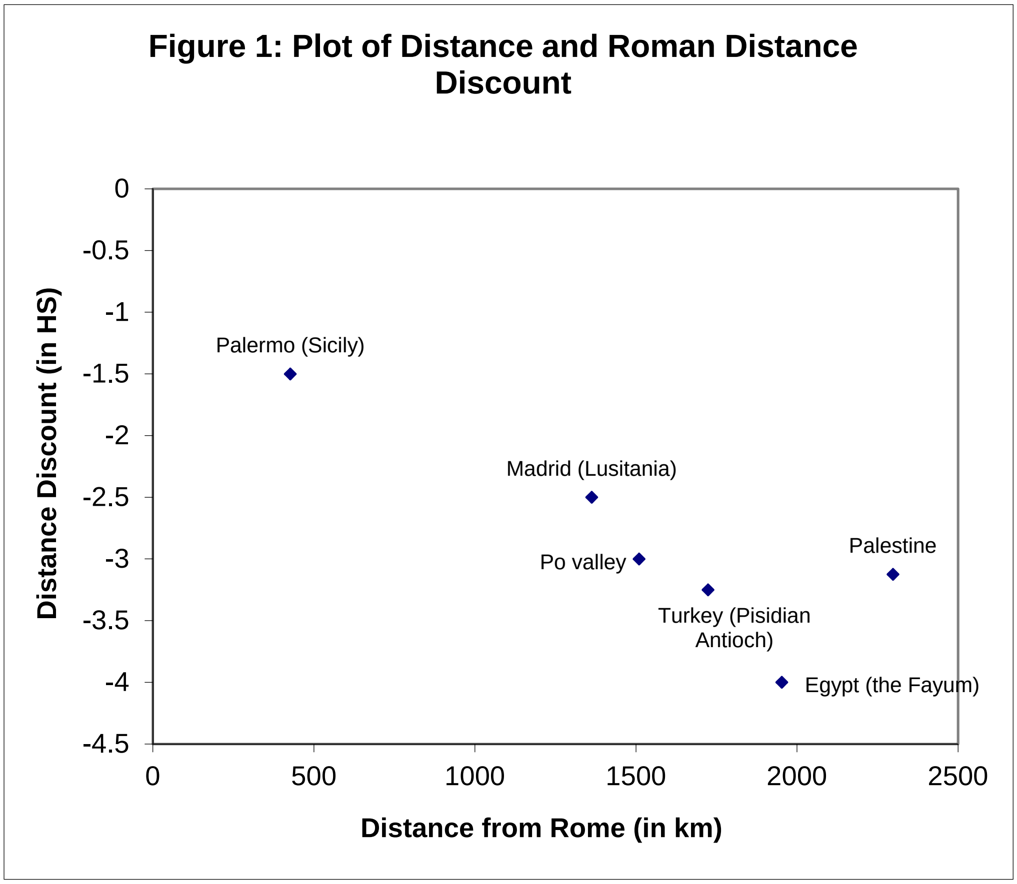

Figure 1: Plot of Distance and Roman Distance Discount
Distance Discount (in HS)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
Palermo (Sicily)
Madrid (Lusitania)
Po valley
Palestine
Turkey (Pisidian Antioch)
Egypt (the Fayum)
0
500
1000
1500
2000
2500
Distance from Rome (in km)

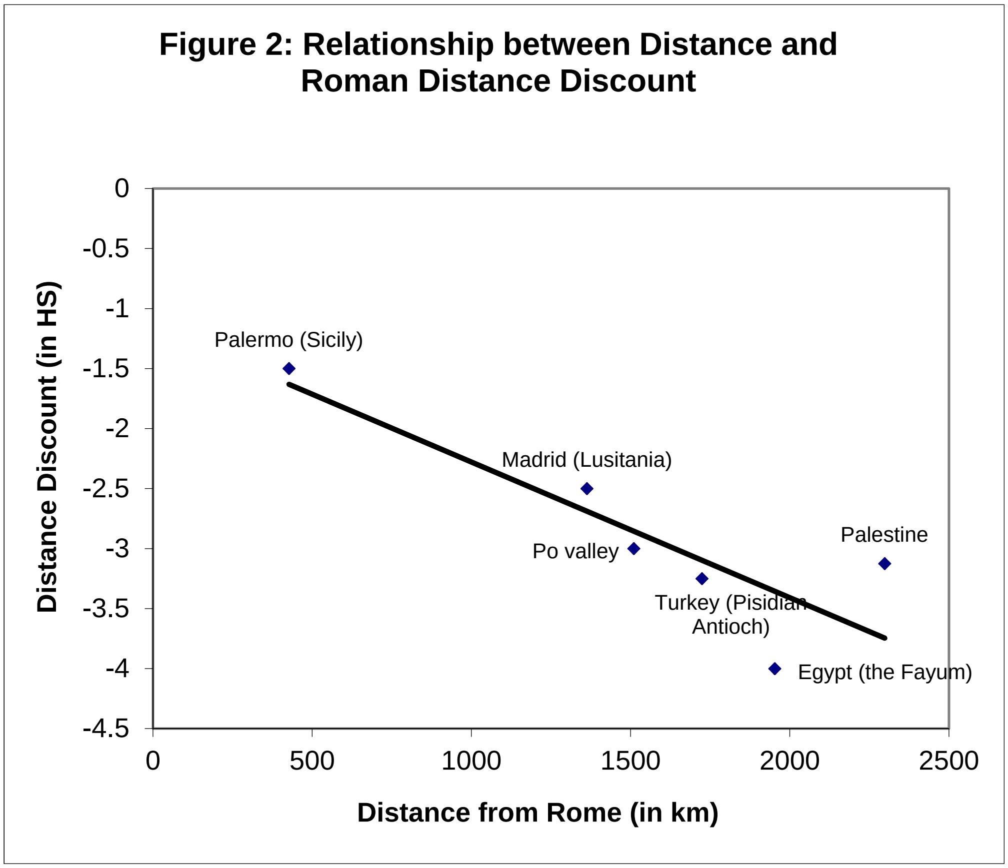
Figure 2: Relationship between Distance and Roman Distance Discount
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
Distance Discount (in HS)
Palermo (Sicily)
Madrid (Lusitania)
Po valley
Palestine
Turkey (Pisidian Antioch)
Egypt (the Fayum)
0
500
1000
1500
2000
2500
Distance from Rome (in km)

Table 1: Distance and Prices for Grain					
Region	**Distance (km) from Rome**	**Rome Price (HS)**	**Province Price (HS)**	**Distance-from-Rome "Discount" (HS)**	**Year**
Sicily (*Sicilia* province)	427	4.00 HS [a]	2.00-3.00 HS [c]	-1.50	77 BC
Spain (*Lusitania* province)	1363	3.00-4.00 HS [a]	1 HS [d]	-2.50	150 BC
Italy (*Italia* province), by River	1510	3.00-4.00 HS [a]	0.5 HS [b]	-3.00	150 BC
Asia Minor (city of Pisidian Antioch)	1724	5.00-6.00 HS [a]	2.00-2.25 HS [e]	-3.13	80s AD
Egypt (Region of the Fayum)	1953	5.00-6.00 HS [a]	1.5 HS [f]	-4.00	20 BC – 56 AD
Palestine	2298	5.00-6.00 HS [a]	2.00-2.50 HS [g]	-3.25	15 AD

Sources: [a] Rickman, 1980, 153-4 [b] Polyb. 2. 15 [c] Cicero, 2 *Verr.* 3. 189. [d] Polyb. 34. 8. 7. [e] *Ǽpigr.* (1925), 126b. [f] P. Mich. II 1271.1.8-38 [g] Frank, ESAR iv, 181 and 183.

Table 2: Rickman Regression Results				
	N	**Constant**	**Distance**	***R^2***
Distance Discount	6	-1.150 (-2.10)	-0.001 (-3.41)	0.74
Distance Discount (No Po Valley)	5	-1.116 (1.76)	-0.001 (3.01)	0.75
Log Distance Discount	6	0.125 (1.52)	0.002 (4.12)	0.81
Log Distance Discount (No Po Valley)	5	0.116 (1.26)	0.002 (3.78)	0.83
Source: Rickman (1980); Table 1.				

Table 3: Rathbone Regression Results

	N	Constant	Distance	Time	R^2
Distance	8	34.8 (5.77)	-.009 (2.13)	.058 (2.15)	.42
Distance (No Po Valley or III)	6	46.6 (4.60)	-.016 (2.30)	.088 (2.09)	.46

Source: Rathbone (2011).

Table 4: Bransbourg Regression Results					
	N	Constant	Distance	Inland	R^2
Distance	12	-2.43 (-7.57)	-.00041 (-3.56)		.56
Distance	6	-0.93 (-8.65)	-00072 (-4.96)		.86
Distance **(with a dummy for inland cities)**	12	-2.78 (-10.16)	-.00050 (-5.37)	0.95 (-2.87)	.77
Distance **(No Antioch in Pisidia)**	11	-2.65 (-8.25)	-.00059 (-4.12)	0.95 (-2.84)	.72
Source: Bransbourg (2012).					